AGE, GROWTH AND SCALE CHARACTERS OF THE MULLETS, *MUGIL CEPHALUS* AND *MUGIL CUREMA*

BY

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Introduction

During the summers of 1915 and 1916 the writer was given the opportunity of studying the rate of growth and development of the mullet of the Atlantic coast of the United States. The collecting was done at and about Beaufort, N. C. Of the two species under consideration, the striped mullet (*Mugil cephalus*) has far the more economic importance. It ranges through all tropic and warm waters of the globe and has long been used as food. On our south Atlantic and Gulf coasts it has been sought so constantly and taken in such quantities that its numbers have noticeably decreased so that the supply continually falls short of the demand. For this reason the artificial propagation of this species is very desirable and it is towards this end that the present investigation has been made.

Differentiation of Species

Along the Atlantic coast from New England to Florida, two species of mullet may be encountered, *Mugil curema* and *Mugil cephalus*, the latter being much the more common. Commercially, no distinction is made although the fishermen seem to be aware of two species, calling the former the "silverside" or white mullet and the other the "jumping" or striped mullet. Other common names are locally used. When asked wherein they differ, the fishermen give a variety of more or less accurate answers, and generally end with some statement to the effect that the "silverside" is very seldom caught. A review of the fisheries literature on these species shows a lumping of the two, so that no accurate information concerning their respective habits can be secured.

Technically the silverside mullet (*M. curema*) differs from the jumping mullet (*M. cephalus*) in having more heavily scaled second dorsal and anal fins, nine rays in the anal fin in contrast to eight in *M. cephalus*, and 38 versus 42 scales in the lateral series and 12 versus 14 scales in transverse (diagonal) series. The field marks are the scalation of the anal and second dorsal fins and a lack of the longitudinal stripes of *M. cephalus*.

Because of the unreliability of single characters in species determination, and because of the possible difference in coloration of adult and young, a study of the variation of specific characters was necessary. Relative measurements in these two species are impracticable as the slight difference in ratios is repeatedly exceeded by individual variation. The amount of scalation on the second dorsal and anal fins is a fairly good character for both old and young fish, but is relative only. The *total* number of rays and spines in the anal fin is not constant. Specimens of *M. curema* with a total of 13 anal fin supports (rays and spines), the last of which may be bi- or tripartite, are not rare, while specimens with 11 supports are rare. *M. cephalus* has ten supports more often than twelve. Thus, though quite constant, this character cannot be wholly relied upon. This leaves the scalation of the two species to be considered.

The mullet is an unusually favorable subject for lepidology because of the relatively large scales and the presence of the lateral line groove (without the pore) which is found on nearly every scale, and which materially aids in the alignment of the scale rows. The general results are that the number of scales in the lateral series varies considerably while the number in the transverse series is very constant. For instance, although *M. cephalus* normally has 42 scales in the lateral series, it often has 41 though as many as 44 and as few as 38 have been found. One specimen was found with 40 scales on the left side and 44 on the right side, two of the extra scale rows were situated between the base of the pectoral fin and that of the first dorsal, while the other two were below the second dorsal. On the other hand a stunted individual 185mm. long whose ratio of depth in length is 3 instead of 4, has 41 scales in lateral series and 15 in transverse series. Each scale, however, is much shorter along its cephalo-caudal axis than scales of normal fish. *M. curema* varies somewhat less. No variation was found in the number of lateral rows (number of scales in transverse series). Thus it would seem that the number of horizontal rows, as in the Ophidia (see Ruthven 1908), is a reliable species character, or at least more so than the number of transverse rows. Owing to the difficulty of counting the number of scales in transverse series of small specimens under a binocular microscope, due to the rotundity of the body and the consequent necessity of rotating the specimen while counting, this character was found impracticable for the determination of large numbers of young, and the scalation was, therefore, further studied. The results are represented in figure 1, which is reproduced from a fairly typical individual. In the absence of a lateral line row the median row on the caudal peduncle was chosen for counting the number of scales in lateral series. The last scale of this row is short and almost hidden by the

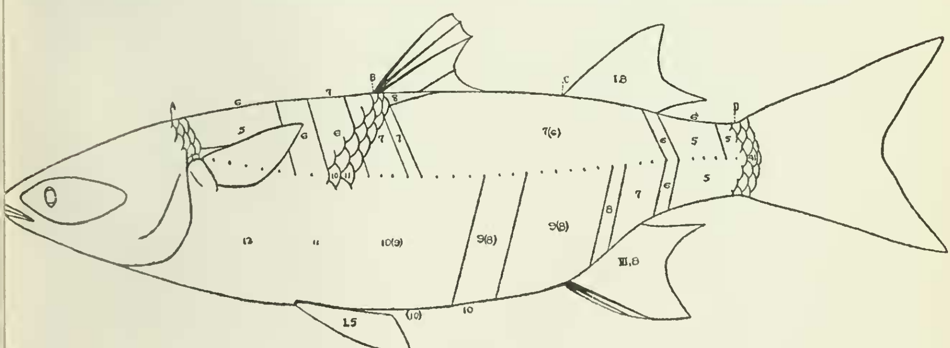

Figure 1. Scalation of the mullet on the side.

forty-first scale. The other scales of the last row become more evident dorsad[1] and ventrad. In the figure the numerals on the lateral median line designate the number of the transverse row, those on the body designate the number of scales in the transverse rows of that area except where a numeral appears above or below the body, in which case the numeral designates the total number, but as one of them is situated on the dorsal or ventral median line, that scale belongs as much to one side as to the other. All numerals include the lateral median line (except those upon it). The numerals in parentheses are the corresponding figures for *M. curema*, (where omitted they are not given). The reason for the diminution of the number of scales in the transverse rows caudad or cephalad is shown in figure 2

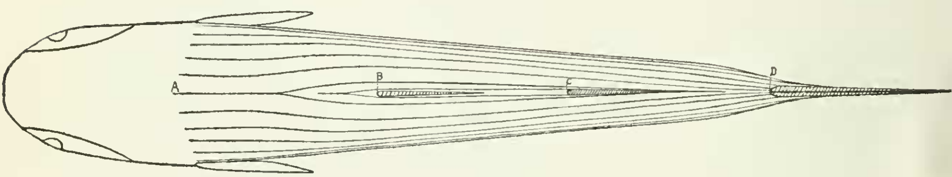

Figure 2. Scalation of the mullet on the back.

which is a dorsal aspect of figure 1 with the lateral line grooves connected by continuous lines. Thus when two lines run together, two scale rows become one row, and where a single line ends, a scale row becomes crowded out. A similar condition obtains on the venter. It therefore seems that reduction of scale rows occurs on the dorsal and ventral median lines—a condition very different from that in the Ophidia (Ruthven 1908). The exact location of the termination of a lateral row varies with the individual so that figure 2 is but individual and the area between *C* and *D* varies in appearance with each specimen. Likewise, there is variation in appearance between points *A* and *B* and the corresponding section on the venter. The area between points *B* and *C* down to, and including the venter, may be definitely relied upon as constant. The transition band on the ventral section (the area between 10(9) and 9(8)) is liable to shift caudad or cephalad a scale or two, but this should cause no confusion.

[1] The termination *-ad* as explained by Wilder and Gage (1882) signifies "towards," "in the direction of," etc.

From this analysis it should be evident that any variation in number of scales in the horizontal row will shift the *limits* of the various areas caudad or cephalad, depending on the individual, and this in turn means that only the middle area is unshifting. This middle area is also so broad that the desired flexibility in counting is given and the possibility of the complete loss of a row is greatly minimized.

A total of forty-four catches made between December 22 and September 4, during several years were plotted on co-ordinate paper using the abscissae for the length of the fish and the ordinates for the date of capture. Simple lines are used for *M. cephalus*, and railroad lines for *M. curema* and *harengus* (see fig. 3). The length of speci-

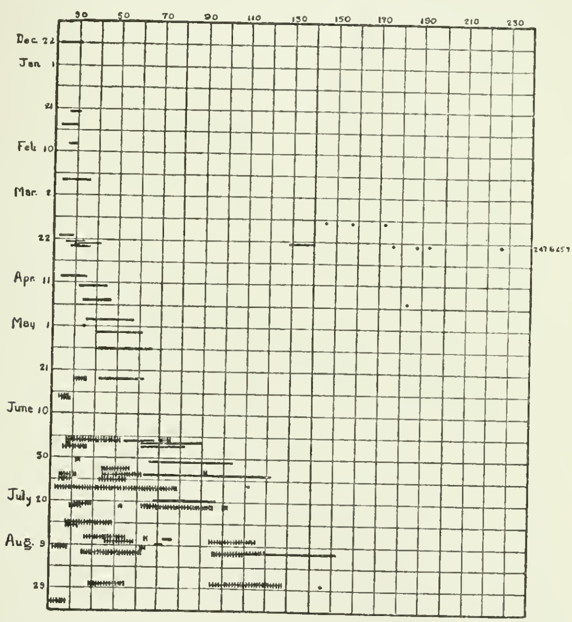

Figure 3. Record of non-linead mullets;
— = Mugil cephalus.
= Mugil curema.

mens herein given is the greatest possible length and all measurements unless otherwise stated are in millimeters.

Mugil Cephalus Linné

Determination of Young

Before anything can be done with the young of *M. cephalus*, it will be necessary to go back to *Myxus harengus* of Günther. In 1883 this species was established as the type of a new genus *Querimana* (Jordan) which differs from the genus *Mugil* in having the following characters—a serrated preorbital, thin lips, no adipose eyelid, stronger teeth and two instead of three anal spines. Bean (1903) has described the development of a third anal spine from the first ray. Further investigation has brought out the fact that the adult also has a serrated preorbital, as will later be described. The condition of the lips, teeth and adipose eyelid will, in the proper place, be shown to be but juvenile characteristics. Thus the genus *Querimana*, consisting of juvenile mullet, becomes a synonym of *Mugil*.

The specimens of *M. cephalus* ranging from 23mm. up to 40 or 50mm. were very carefully examined and were found to be juvenile *M. cephalus*, a heretofore undescribed *Querimana* (having the "Querimana" formula of A. II, 9; scales 42–14).

The specimens running into the *M. curema* group answer perfectly to the description given for *Q. harengus*. The description of *Q. harengus* (Jordan, 1896), gives it thirty-eight scales in the lateral series, twelve in transverse series and an anal fin formula of II, 10. Adulting (changing to adult condition) this fin formula according to the evidence given by Bean (1903) we have A. III, 9. This agrees with *M. curema*. The development of *Q. harengus* further shows it to be the young of *M. curema*, as will be shown below and not a distinct species.

Development of Young

The juvenile stage of *M. cephalus* begins with individuals as small as 23mm. Their first appearance is in the form of well developed fish without the slightest larval appearance. As already described by various writers, they form compact schools, swimming near the surface of the water. They may be found in deep water, or more often in water but a few inches in depth. The time of the year during which they are to be found may best be seen by consulting figure 3. They might easily be mistaken for the young of *M. curema*, because of the similar coloration. Collections made from December to March consist of slim silvery individuals of small size. There seems to be very little growth during this time. The sides are devoid of pigment, being sharply defined from the dark brownish-green back. In later March and early April this dark dorsal band is extended down the sides by the gradual appearance of pigment cells. By mid-April these pigment cells have so increased as to merge the dark back into the silvery venter. With this advance in color, the fish rapidly increases in length and the abdomen is bulged by the developing intestine. Besides these external evidences of a turning point in the life history of the species, the growing parts of the fish show this change, though some more strongly than others. In the following the juvenile characteristics of this species through the development of the fish to its adult form, this turning point has been noted and the reason sought. The lengths of the fish as given below are used for the purpose of correlating the development of the various parts with with the fish as a whole, and are of typical specimens. The silvery (or juvenile) stage is found in specimens from 23 to 32mm. in length, while those from 30 to 35mm. are somewhat difficult to distinguish as silvery or dusky because of the merging of the two forms at this size.

The *preorbital* in the juvenile stage has some 10 or 12 points, teeth or serrations, of fair size. As the fish grows these points become more and more numerous, less slender and less distinct. In older fish they become blunt and stocky until in a large individual (502mm.) there were 53 teeth on the margin, crowded so as to place about four to a millimeter.

The *adipose eyelid* shows no marked acceleration in rate of growth at the end of the silvery stage. It is entirely lacking in the smallest specimens, but by the time the fish has reached a length of 28mm., with the aid of a high power binocular microscope, a slight translucent growth can be detected just anterior to the eye. In describing the state of transparency of the eyelid, it must be remembered that only alcoholic specimens are being described, in life the adipose eyelid being perfectly transparent at any age. For the sake of convenience the eyelid has been divided into three parts: (a) the ring, which is situated about the rim of the orbit, (b) the anterior lobe, and (c) the posterior lobe. When the fish is about 30mm. long, the anterior lobe having slightly thickened, has become semi-translucent and has stretched backward over the eye. At 32mm. length, the anterior lobe has further thickened and become slightly more opaque, stretching farther back over the eye and merging into the ring which has just become visible. By the time the fish is 36mm. long, the anterior lobe has become opaque, while the ring, which has very slightly stretched posteriorly, has become semi-translucent. From this stage, the gradual development of the growth can be easily followed without the aid of the microscope. At 39 mm. the posterior lobe has become quite definite while the anterior has thickened and become more nearly opaque. On 42mm. specimens, the anterior lobe is visible to the unaided eye. The ring has assumed an opaque cast at its inner edge and stretched out over the rim of the nearest scales. The posterior lobe has, by now, spread out over the preopercle but is still translucent. The growth of the orbital ring is now very slow, its chief expansion being inward over the eye. In a specimen 47mm. in length the posterior lobe has become so opaque as to become visible to the unaided eye. Its lateral growth takes it not farther up or down than the outer diameter of the ring, while its chief growth is posteriorly over the preoperculum. The anterior lobe grows no farther forward, having reached a point just anterior to the nostril, but it slowly grows out over the eye. At 54mm., the more rapid growth of the lobes has caused them to overrun the ring anteriorly and posteriorly, so that the ring now assumes an elliptical shape, the long axis of the ellipse being vertical. Sixty millimeter specimens show this ellipse more strongly developed, the posterior lobe much lengthened posteriorly and the whole eyelid in its typical form, so that it is now only a matter of slow growth before the adipose eyelid has assumed its maximum development in the full-grown adult. Thus it is seen that there is no break between the juvenile stage and the adult.

The *thin lips* given as a characteristic of the genus *Querimana* do not appear disproportionally thin for so small a specimen. If there is any relative thickening of the lips beyond normal development, it is so gradual as to be imperceptible.

That *the teeth* are slightly stronger in the juvenile young than in the adult cannot be considered a generic difference in itself, as it may well be due to a retrograde modification due to change in food habit; as there seems to be grounds to suspect is the case.

The development of *the third anal spine* from a ray was described by Bean (1903) but deserves further comment. The ray is simple and has about four articulations. At the close of the juvenile stage

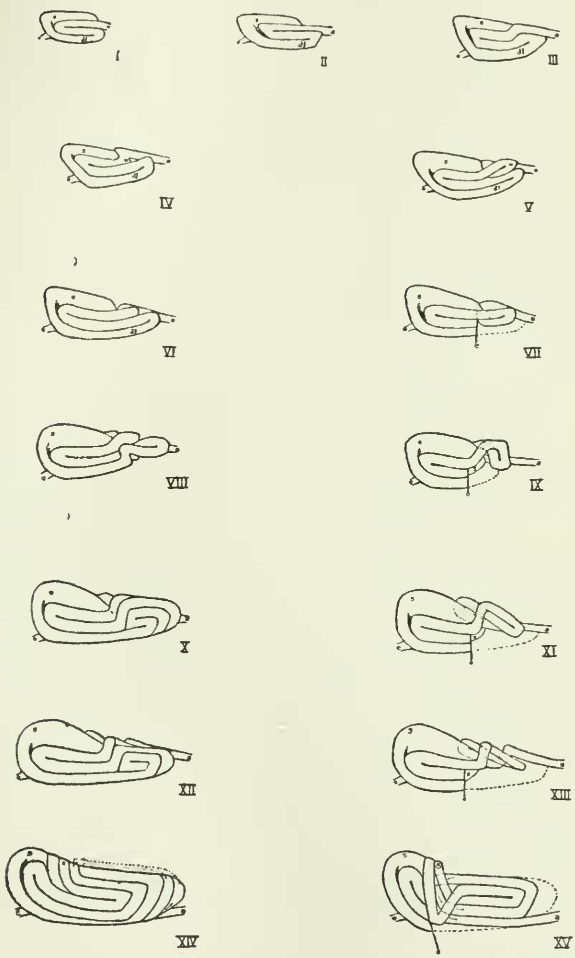

Figure 4. Development and convolutions of the intestine of *Mugil cephalus* when from 23 mm. to 40 mm. in total length. s = stomach; e = esophagus; a = anus; c = line of cut of duodenal loop, see p. 208. At figure v the fish is 32 mm. long and transforming into the dusky stage.

this ray ceases growing with the same rapidity as the true rays and becomes heavier basally, continuing to become relatively heavier and stiffer, until it is about one-third of the space between the tips of the second spine and the first ray, longer than the second spine spine (Fig. 1). This relative length is maintained throughout life. As this spine continues growing and thickening, the articulations become obliterated until lost so that in adults the third spine is basally as heavy as the second and quite equal to it as a spine. This development should be of much interest to the morphologist and systematist.

The *reproductive organs* are so rudimentary as to be invisible throughout any part of the season or at any point in the juvenile stage. This might be sufficient reason in itself for discarding the genus *Querimana.*

The *development of the intestine* gives further evidence of the relations of the two forms. Owing to the difficulty of describing this development a series of outline sketches (Fig. 4) have been prepared, illustrating, by a lateral aspect, each successive change.

The most simple form (fig. 4, I) consists of a duodenal loop and a "straight-away" to the anus. When the figure V stage is reached the fish is passing into the dark or dusky stage, the kink *n* having lengthened into a loop whose lower member has twisted upward and over its upper one to form a loop. At the next figure (VI) the spleen appears as a yellowish body, 25mm. in diameter, and from then on becomes a factor in influencing the convolutions of the intestine. At the figure VIII stage the duodenal loop makes a kink which soon becomes a loop and thus destroys the duodenal loop in its typical form. Each odd figure from VII to XV shows the convolutions on the further or inside by the cutting away of the duodenal loop or its modification at line c. Beyond the stage shown in figures XIV-XV the convolutions become so intricate that their study would surpass the scope of this paper, the length of the fish at this time averaging about 40mm. Thus, in the lengthening of the intestine, there is a marked acceleration in the rate of growth at the time when the fish is about 32mm. long, i.e., when the fish is passing into the young or dusky stage.

Besides this development in length and complexity of the intestine proper, the whole abdominal cavity is eloquent of the change externally noticeable. To appreciate this change, it is necessary to begin with the earliest individuals. All December specimens examined had their entire viscera and the walls of the abdomen colored orange, while the peritoneum in many cases was grayish with dark spots, otherwise it was of a semi-translucent blackish color. The length of the intestine was at times half that of the individual itself, though generally about three-quarters its length. In January, the coloring of the intestine was the same as for the previous month with the exception of a few individuals in which it was yellowish while the peritoneum averaged darker, and the walls of the abdomen a little lighter. The length of the intestine showed a slight increase over specimens of corresponding lengths of the previous month. In February the viscera were yellowish to pale, a very few individuals having traces of vegetable matter in the intestine. The peritoneum showed no special change, while the walls of the abdomen were pale. The intestine, on an average, had increased in length to a slight extent, but in no cases equaled the length of the individual. In late March, quite a few specimens had entirely lost their internal orange or yellow color and the intestine had traces of dark matter. The peritoneum was black and the flesh about the viscera had assumed the more natural dark coloration. These specimens showed marked increase in length of intestine, it being considerably longer than the individual. These fish were passing into the dusky stage. The majority of specimens, however, were much like those of the previous month. The viscera of April specimens are rarely orange or yellow tinged, the great majority having the intestine more or less filled with dark matter. The length of the intestine had also correspondingly increased. These fish were well into the dusky stage, their intestine appearing as represented in VII to XV of figure 4. It was from these slowly developing individuals that material for figure 4 was taken. From this time on the growth of the fish is very rapid in comparison with that of the previous month. Thus the increased length of the intestine can be directly correlated with its own color.

An explanation for the change in visceral coloration described in the preceding paragraph was sought by examination of stomach contents. The silvery-sided individuals (juvenile fish) showed an almost exclusive diet of crustacea, mainly copepods, and as alcohol almost invariably turns this form of life a salmon red, the coloration of the viscera is accounted for. The intestine as well as the stomach were filled with this food, the latter not yet having reached the gizzard development. In the most immature individuals the stomach's form was that of a simple sack. The stomach contents of the dusky stage consisted, roughly, of 40% sand and mineral matter and 60% vegetable and animal matter. This latter consisted of 50% diatoms, 35% algae and other soft vegetable matter and 15% animal miscellaneous. This seems to be the usual ration of the fish during the remainder of its life, it being known as a mud feeder (See also Linton 1913).

From the above, two things should be apparent, namely (a) that the first form (the juvenile or silvery stage) develops into the second (the dusky stage), (b) that the juvenile stage is one of slow growth and development which is more rapid after the fish has changed diet, (made evident by the change in the color of the viscera). Because the intestine, the stomach and the whole fish acquire an acceleration in rate of growth and development at the time of change of diet, we conclude that this period of change is due to change of diet.

A study of *the development of the scale* along with the development of the individual is essential to the correct understanding and interpretation of the adult scale. The simplest form procurable is found in the juvenile or silvery-sided individuals (figs. 8–9). Text figure 5 represents one of these scales (in its natural position) divided into areas using Masterman's (1913) method. Rather than deal with the axes, greater convenience is found in using the areas formed by these axes as designated in figure 5. The terms "dorsal" and "ventral" have not been used as no need was found for this differentiation of sides. In the scale work here presented the scales were taken from the lateral median line on the two rows originating at the latero-anterior edge of the first dorsal fin (scales 10 and 11 of figure 1), except in the very young, where this was done as nearly as possible. For convenience, the appearance of the scale is described by means of a formula in which *a*, *l* and *p* stand for the anterior, lateral and posterior areas respectively, while the number following each of these refers to the number of circuli in that area. Thus, the formula for the scale of figure 5 would be a. 11; l.0; p. 22. The two lateral areas generally differ in number of circuli when these are present; the average has then been taken. In the more advanced stages of growth the number of

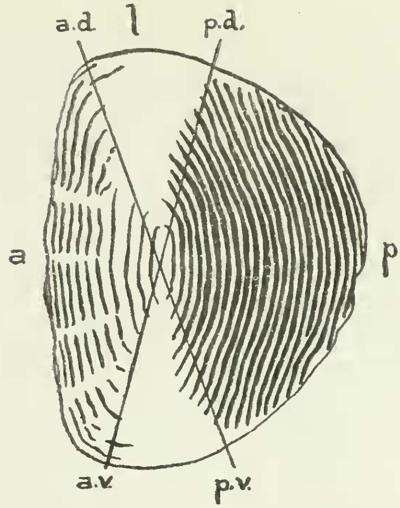

Figure 5. Advanced silvery stage scale, x45 divided into areas. a. v. =antero ventral axis; p. v. =postero-ventral axis; a. d. =antero dorsal axis; p. d. =postero-dorsal axis; l. =lateral areas; a. =anterior area or basal end; p. =posterior area or apical end. Formula=a. 11, l. o, p. 22.

circuli on the lateral area was computed by finding the average from two or three scales (taken from the place above mentioned from one or both sides of the fish). This does not affect the general result as whatever variation is shown in these four scales is about as great as the difference between the scales taken from corresponding places of two different fish of the same size from the same school. In other words, it was found that the average number of lateral circuli of scales 10 and 11 from fish number one was more constant than the average number of lateral circuli of scales 10 and 10 from fish number one and two (both being of the same size and from the same school). With this, it must be remembered that the number of circuli does not represent the number of "days" of growth, but that they testify to the approximate *development* of the individual. The formula, then, is useful in conveying a fairly good idea of the size and amount of development of the fish from which it was taken.

The smallest fish have a scale already well developed, a 23mm. specimen having a circuli formula a. 7; l. 0; p. 15 (fig. 8). This being the type of scale showing the least growth of any procurable, it is inferred that the greater portion of this scale was formed at the spawning grounds. Notice on this scale, (a) that the circuli on the posterior area are much closer together than those of the anterior area, (b) that the lateral areas are without circuli and (c) that the circuli nearest the center are farther spaced than those further out. As the scale enlarges, more circuli form on its anterior and posterior edges, until the scale has reached a maximum development of a. 11; l.0; p. 22 on a fish of 32mm. length. This type of scale may be found on any silvery-sided individual, i.e., during the months of December, January, February, many in March, and a few in April. The addition of circuli during this season is very slow, so that the scale in three months' time, shows no more advance than illustrated in figure 9. Very often the scale shows less development than this before the juvenile stage comes to a close. From this point, the method of growth of the scale completely changes. Figure 10 shows a scale whose formula at the silvery-side stage was a. 10; l.0 p. 20. A little later two *closely spaced* anterior circuli were added, and, while this was going on, the tenth anterior circulus stretched back along the outer rim of the scale, thus forming a lateral circulus, so that the formula of the complete scale has become a. 10+2; l.0+1; p. 20, and the posterior edge of the scale shows a narrow border without circuli. In the next figure (11) three anterior circuli have been added to the juvenile scale, two of which have become lateral; the posterior border is quite wide but without definite circuli. Note the shallow depression just posterior to the center. This is the beginning of what is, in some fish, known as the lateral line groove, and in this paper will be referred to by this term. Figure 12 has two more anterior circuli, an additional lateral circulus, a broken or fragmentary posterior circulus with suggestions of a second, and a larger lateral line groove. Note the fine reticulations at the anterior edge of the posterior circuli. The fish from which the scale of figure 11 was taken had a length of 38mm. The circulation is still further advanced giving the formula a. 9+10; l.0+4 or 5; p. 19+1(or 2). The lateral line groove almost obliterates the first few posterior circuli and the reticulation or veining is more extensive and better developed. This series should clearly show the way the scale changes its habit of sculpture (habit of growth of the configuration of the surface). Figure 14 shows a scale from a 45mm. individual and gives the effect of this new development. The juvenile scale is seen to be completely encircled by the later more rapid addition of circuli which *tend* to be continuous. Thus, the scale is of the cycloid type. Note, (a) that the anterior circuli are almost twice as numerous as the lateral, their ends terminating near the anterior axes, (b) that the anterior circuli of the outer series curve in the opposite direction to those of the juvenile scale, thus making a definite demarkation between the two scales, (c) that in the outer series the closely spaced circuli are anterior while they are posterior in the juvenile scale, and vice versa with the widely spaced circuli, so that in this respect the habit of sculpture is reversed. This change, although taking place at the same time as a change in diet, and occurring during the months of March and April, is not due to seasonal or dietal change, for the scale of *M. curema* passes through the same change at a different season (during the summer) and unaccompanied by a change of food. It is therefore inferred that this change is due to some previous change in habit of growth of the scale, i.e., the change is phylogenic.

During this development the juvenile scale which is designated by various authors as the nuclear area, nucleus,[2] centrum, initial field, etc., occasionally passes through a process of deterioration of surface face sculpture. This begins with the veining just anterior to the posterior circuli (figs. 11–14) spreading farther and farther until the lateral areas are covered (figs. 17–19). When the lateral areas are fairly well filled in, the posterior circuli are gradually replaced by the veining so that the veined area is linear or ovate in shape and not the shape of the scale. A process giving a similar aspect has been described and accounted for by Dahl (1911, p. 11–13).

The addition of circula continues more or less regularly for a longer or shorter time according to the individual. Figure 15 illustrates a scale taken from a 60-70mm. specimen, and serves to show the nature of growth of the apical or posterior circuli. Note the way in which the posterior circuli are bending out toward the apex of the scale. With the bending out of these circuli the scale grows more rapidly at the apex and on this posterior lobe narrow, pointed, posteriorly directed cteni gradually rise from the surface. These cteni are firm and strong, much longer than wide, slightly bent to give

[2] It seems preferable to reserve the term "nucleus" for the structural center of the scale as used by Cockerell (1913).

more rigidity, and sharply pointed (figs. 20, 25, 27). These cteni continue to form row after row, the scale taking on the appearance of the one illustrated by figure 20. This scale (removed from a fish taken on the 23rd of August) contains all the characteristics of the species although the individual was but 145mm. long and not yet one year old. The lateral line groove has extended backward to the posterior margin of the juvenile scale and forward as a narrower channel to its anterior margin and to the posterior end of one of the basal radii. This linear shape is that assumed by the lateral line in the adult. In figure 22, although the scale shows nearly the same amount of growth, the cteni have not as yet begun to form. Before the further development of the scale is noted, it will be necessary to review what is known of the migration of this fish.

Migration

The earliest reliable information we have concerning the migration of the mullet is a note left by Dr. Yarrow (Smith 1907) on the fish in the Beaufort region in 1871. The substance of this note relative to migration is that small-sized individuals appear in May, and that in later August fish commence to school preparatory to migration. He says:

> The schools appear to come from the northward through Albermarle, Pamlico, and Core sounds, gradually working their way southward. Their departure through the various inlets seems to depend upon a favorable state of the wind, which should be from the northward, for it has been noticed frequently that when the wind hauled, the schools of mullet already without the harbor have suddenly turned, re-entering the inlet, and pursued their course southward through Bogue Sound.

A few years later the U. S. Commission of Fish and Fisheries sent out Mr. Ravenel (1887) to find out what he could about the mullet. The method pursued was to visit various fishing centers and consult the fishermen. The only reliable information we need note is that at Beaufort three "runs" were noted as follows:

small mullet 4–5 inches		June–Aug. 30.
fat	"	Sept.-Oct. 10.
roe	"	Oct. 10–Nov. 15.

The same year the Commission issued its comprehensive work on the fishery industries in which there are two papers on the mullet. The first one (Goode 1887) treating of the natural history will not be considered as it is based almost entirely on hearsay but on the second (Earll 1887) which is much more comprehensive and reliable. From under its caption "movements" the following general notes have been extracted:

. . . Small sized individuals are scattered about on the feeding grounds in the grassy bays and marshes bordering the coast. Here they remain till late in July, when they proceed to the deeper channels of the larger bays, where they gather in schools of small size. Little is known of the whereabouts of the large mullet at this season. Later the migrations begin, the fish of medium size moving southward. Their places are soon filled by large fish. . . . These (roe mullet) remain until the first cold storm occurs, when they start for the south, moving rapidly along the outer shore, or through the inland passage. These fish are followed by smaller individuals known as "frost mullet," which remain through the greater part of the winter. The movement seems to be general along the entire coast, all fish along the Atlantic seaboard being reported as traveling southward, while those rounding Florida Keys continue their coastwise migrations, gradually working northward and westward towards the Texas line. No return movement is reported at any season along the Atlantic. . . .

In N. J. waters the mullet make their appearance in schools about the first of September, gradually working southward and entirely disappearing by the last of October. The same is true for the coast between Cape May and Cape Henry, including the waters of Chesapeake Bay.

The small fish are seen in June on the N. C. coast, these gradually increasing in numbers until the first of August, when the schools have attained considerable size, but thus far no tendency to migration is noticeable. A little later a southern movement begins, and school after school passes, the size of the individuals constantly increasing till the first of September when the old or roe mullet arrive. . . If the weather continues pleasant they remain along the shores until the eggs have become well developed before moving southward, but at the approach of the first cold storm they are off and other smaller individuals follow in their wake, so that by the first of January the greater part have disappeared. Comparatively few are seen from that date until the following June, though scattering ones may be taken at any time.

At Wilmington [N. C.] small mullet are occasionally taken at any season, though they are abundant from June to September only, and large ones are seen only in the fall. As at Beaufort, the migration begins about the middle of August. The first schools are composed of fish of medium size. . . . By the first of September these have entirely disappeared, and their places have been taken by the "fat mullet." These are very abundant for several weeks, the roe mullet arriving about the middle of October, before they have entirely disappeared. "Frost" or "inch" [the distance between the eyes] mullet, as they are sometimes called, follow in large, compact schools, the last disappearing about the middle of December. Smaller fish, called "winter-mullet," are abundant till spring. . . .

At Charleston the run is somewhat similar to that at Wilmington.

In East Florida, especially the St. John's River, fish of all sizes may be seen at any time. . . .

> In the Gulf of Mexico it is claimed that the mullet are even more abundant than along our Atlantic coast. . . . They are never entirely absent, though, as on the Atlantic coast, they are much more abundant in the fall than at any other season. . . .

From the evidence at hand it is clear that the mullet fisheries for different parts of West Florida continue from the middle of August to the first of January, though the height of the season, for most localities, is in October and November. Farther west the fish seem less inclined to migrate, remaining more constantly in any given locality, and on the Texas coast it is said that there is no special time of abundance, but that mullet are equally plentiful at any season.

Notes on Wood's Hole (Smith 1897) state that *M. cephalus* is "Found from September to end of October, going in large schools about October 1." For the same region Sumner (1911) reports *M. cephalus* as "Present from July to December; most common in the fall." In summary, Bean (1903) states that about New York the earliest appearance of *M. cephalus* is in August when they are few, that in September they are found in the New York markets and that "the great schools were absent till October."

The two most striking facts brought out by this literature are those of a fall migration and the almost complete absence of large mullet on our coast during the later winter, spring and early summer. This migration seems to begin at the northern extremity of the range of the species and extends southward with the migrating fish. The migration seems to be orderly, deliberate, and in series, each series being made up of a certain age group, almost the whole coast load of mullet slipping around the peninsula of Florida and along the gulf coast before all have scattered through the more torrid water which is the real home of the mullet. Thus, there can be no question about a definite fall migration down the Atlantic coast to warm water. Another thing to be noticed and borne in mind is that the migration is slow and leisurely, taking at least three months, so that it would seem that each individual had time to live at its leisure on the way south. Finally, notice should be taken of the lack of any noticeable northward migration. Thus nothing is known of the fish from the time it reaches the gulf until it reappears in late summer. There can be no doubt that the fish does not return north during the winter, but that it is living in southern waters where it can feed unrestrainedly. After the winter therefore, in spring or early summer, this species must return north. For a possible record of this period of the life history of the fish, the scale may again be studied.

At the time that the young are from 40 to 60mm. long or about the beginning of May, individuals of another age-group, as small as 120mm. in length and up, make their appearance. These individuals keep increasing in size and numbers throughout the summer so that by the end of August they are very common and range from 220–370mm. in length. Their scales are all characterized by the single "line" or break in the continuity of the circuli typically illustrated in figure 25. The fish from which this scale was removed was taken on July 2 (1915) and had a total length of 218mm. Notice (a) the deterioration of the sculpture in the center, (b) the ctenoid area and the position of the sharpest and the most worn teeth, (c) the unpored lateral line groove, (d) the continuity of the "line" from the lateral area posteriorly to and into the ctenoid area, and anteriorly across the anterior area, (e) that the "line" is formed (1) laterally by the termination of the circuli in exactly the same way as they are terminated at the outer edge of the scale, and (2) anteriorly by the termination of the circuli in exactly the same way as they terminate at the anterior edge of the scale, (f) that this "line" is the so-called "winter-line" and (g) that the circuli within the "line" are all equally spaced. With the last three points (d, e, f) in mind as well as the fact that this is a south wintering fish, let us consult the scales of fish which remain in cold northern waters during the winter. Good illustrations of such scales have been published by Gilbert (1913), Mastermann (1913), Lea (1913), Nilsson (1914) and Hjort (1914) of the salmon, herring, mackerel and cod respectively. In the scales of the salmon and cod, close examination will reveal that the winter area is formed by the crowding together of the circuli (the circuli of the cod are broken into dashes). The mullet scale is entirely lacking in the crowding of circuli, testifying to undimished feeding during the winter. The herring and mackerel scales, due to non-concentric circuli on the older section of the scale show an entirely different type of "winter line." In this case it is formed by the pinching out of the circuli. Thus they cannot be used to compare with the mullet. Now, since the mullet is not affected by winter conditions and does not show the typical winter crowding of the circuli, another cause must be sought for the break in the sequence of the circuli which does occur. As already pointed out, this break is exactly similar to the break caused by cessation of life. The break is sudden and complete. We advance the hypothesis that this line is caused by a spring migration differing from the fall migration in being made (typically) by a continuous run and not by a slow gradual shifting as in the fall. Various types of these "lines" or linea[3] may be encountered. Figure 25 illustrates its more typical and usual appearance, i.e., when the linea is similar to the periphery. An occasional type of linea consists of a straight but wide space between some two lateral circuli. In one scale examined practically all the pre-migratory lateral circuli had slightly shifted laterally and continued posteriorly as post-migratory circuli. This may have been due to a migration of such a nature that growth was retarded, not entirely stopped. Figure 24, if closely examined, will show two closely spaced lineae, the outermost being the most distinct. Such a form is occasional and may be due to a second migration several weeks after the first, the fish going still further north. Thus, the actual number of lineae cannot be absolutely relied upon for the age of the individual Furthermore, one cannot consider every linea a migration line as any cessation in feeding or growth for any reason whatever, might cause the interruption and renewed growth of the scale necessary to form a linea. Therefore, though the actual number of linea is not always reliable for the determination of the number of seasons which the individual has passed through, the linea may be relied upon for age determination when properly understood. Before this can be done, however, the development of the scale of the species must be studied along with the development and life history of that species.

The above mentioned hypothesis seems to be further substantiated when one notices that specimens from 129 to 257mm. long (clearly of a second age-component (fig. 3) having as many as 70 lateral circuli outside the juvenile scale) were taken in March. The lateral circuli of the scales of these individuals were all evenly spaced

[3] From the Latin *linea*, -ae, f; using the term in its more figurative application. I introduce this new term to specifically label the definite feature of the scale typically illustrated in figure 23 and explained above, restricting the terms peronidia, annuli, winter band, annular ring, etc., to the area of circuli between the lineae or between the first linea and the juvenile scale.

and no linea of any kind could be detected, yet they were passing through or had just passed through the winter, evidently at or in the general vicinity of Beaufort. Thus, all mullet do not leave our coast, those here in winter having probably come from much farther up the coast. Furthermore, no fish with a single linea were taken before late April which could at all be considered of this second age group (or younger). The fish scale from which figure 23 was taken was removed from an individual taken on the 28th of April. The linea is some three circuli from the margin of the scale, thus setting the date of migration during the earlier part of April. Other specimens taken during the spring have the following number of post-linea circuli:

May 2—2 and 4
May 4—4
May 11—7
May 12—0, 3, 6, 6, 7, 7, 7, 10
May 25—3 and 10

Allowing an average accretion of five circuli per month, this data gives early April as the norm of migration. That it is general and fairly definite is brought out by figure 6, which is the record of the

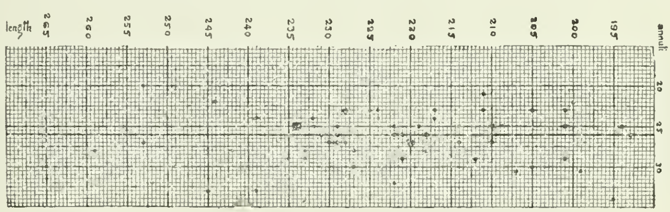

Figure 6. Record of Postmigratory annuli of Jumping Mullet caught July 10, 1915.

number of post-lineal circuli of a catch made on the tenth of July of one linead mullet. The fish being all taken on the same date, any variation of the date of migration should be shown by the number of circuli. The abscissae give the number of circuli and the ordinates the length of the specimens; the points of greatest magnitude designate three specimens recorded at that point, etc. Although there is a variation of 14 circuli, or nearly three months, it is not necessarily all due to difference in date of migration, for individuals vary in rapidity of accretion of circuli, i.e., in a given time one individual may acquire x circuli while another would acquire x+3 or 4. However great or small a variation in time there may be, figure 6 clearly shows that there is a definite time of migration which, as has already been shown, takes place in earlier April and normally consists of a single continuous run from southern feeding ground to more northern waters. That the fish migrate in deep water off the coast seems evident from the fact that the fishermen are unaware of such a movement and that the fish is practically neglected by them until the fall migration.

Second Age-Group

The arrival of the jumping mullet in April marks the beginning of its second season on our Atlantic coast; its age ranges from 14 to 17 months and its size from 120 to 200mm. (5 to 8 inches) (see figs. 3

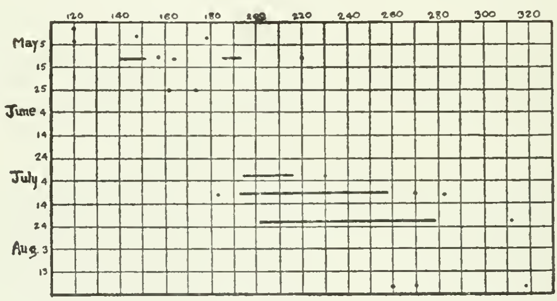

Figure 7. Record of one linead mullet.

and 7). "The individuals are scattered about on the feeding grounds in the grassy bays and marshes bordering the coast" (Earll 1887). They can be found in small numbers over any mud bottom, mud flats, etc., where vegetable plankton is abundant. Specimens may be secured at any time during the spring and summer but they are so scattered as to make fishing for mullet alone an expensive proposition. Living thus they grow to a length of from 225 to 325mm. by mid-August. Their flesh is very soft and oily, hence their name "fat mullet." By this time they have begun to gather into schools of ever increasing size, the social instinct becomes dominant as the reproductive organs rapidly develop. By late September the southward migration has begun and as the fish move down the coast and the roe ripens, they spawn. Out of a batch of ten roe mullet purchased at the Beaufort market on October 9, 20 and 25, four had but a single linea as follows:

Length of fish 410,	Scale formula 1.68+50[4]
414	1.63+45
426	1.57+57
431	1.69+57

The remaining six each had two migration lines giving the following scale formulas:

Length of fish 426,	Scale formula 1.42+60+28
440	1.51+44+21
454	1.43+45+24
473	1.40+50+28
483	1.47+55+24
493	1.60+46+23

The small number of circuli acquired during the third year indicates that the rapid growth of the fish had been partially checked by having attained sexual maturity—as is usually the case. If the series examined was typical, and every effort was made to make a very general choice, this would mean that the jumping mullet generally attains maturity and spawns for the first time in its second year. That this is not always the case is evident from the scales of a male 392mm. long with testes 34mm. long and 7mm. wide, taken on July 12 (1915). The average number of lateral circuli for two or three scales reads 1.38+72+8, which means that it was spawned late in the season, that it probably migrated north early the first year, late in the second and in its third year was maturing early. No other fish was taken with reproductive organs so far advanced, so early in the year; the time of the year for organs of that size normally being in mid August.

Adults

According to scale evidence, the majority of jumping mullet breed for the first time during their second year. At this time they average

[4] As it is unnecessary to mention the number of circuli in the anterior area or in the juvenile scale, the formula for older fish need include only the number of circuli in the lateral area using a + sign for the linea.

less than a foot and a half, and constitute the great bulk of the mullet fishery. The largest mullet that has come under our observation is a 502mm. (20 inch) roe mullet whose scale (fig. 26), shows it to have been in its fifth year. Some individuals are reputed to attain a length of two and a half feet and a weight of ten pounds. What may be said concerning the average adult mullet applies equally well to the larger individuals. Those which return in the spring pass the time in the marshes, mud flats, and mud bottoms of the wide shallow estuaries, sounds, etc., so characteristic of our sunken and inundated Atlantic slope, at least as far north as Cape Cod. The colder temperature and rugged coast extending from Maine northward forms a highly efficient barrier for such a highly specialized fish as the mullet. In its spring and summer feeding grounds it can thrive secure from man for it is so scattered as to make seining unprofitable and it is in a practically inaccessible locality due (a) to the soft muddy bottom in which it seeks cover and in which man sinks so as to make seining impossible, (b) to the reeds and grasses over which the lead line will continually rise and allow the fish to run under—not to mention those which clear the floats with three to eight feet to spare, and (c) to the inaccessibility of the locality to power boats. Such is the choice feeding ground of the mullet, and such is the locality from which this fish returns to deeper water, fat and full, to enjoy a more gregarious and social life. As the schools increase in size and the temperature of the water lowers, their reproductive organs having developed, they move slowly down the coast *en masse* both outside and inside the Banks, spawning as necessity demands. At Beaufort roe mullet are rare in September, common in October, abundant in late October and early November, and rare in December; they are caught both inside and outside the banks, though (according to the fishermen) never with the eggs running (prime ripe); while spent mullet are found wherever mullet are to be found. Some of the fishermen attribute this lack of "running" roe mullet to their going out to sea to spawn while others claim that they spawn in fresh water because the young are found there (although they are equally abundant all the way out to well beyond the shore line). Thus nothing is known of the spawning grounds of this species and therefore of its eggs or larvae, the earliest stage known being the already well developed young described at the beginning of this paper.

Mugil Curema Cuv. & Val.

Young

The young of the white mullet, as above shown, is the so-called *Querimana harengus*, and is undoubtedly found as far north as Wood's Hole. At Beaufort they have not been recorded earlier than May 25th, but there is reason to believe that they could be found even as early as late April. In habitat and habit they are similar to *M. cephalus.*

The *development* of this species is, in general, like the former, but without a definite silvery stage and with a constant rate of development of the various parts and of the individual. The smallest specimens normally procurable are 20 to 21mm. long and as much developed as are 23mm. specimens of *M. cephalus.* At this least size the alimentary canal contains no trace of the crustacean diet so characteristic of the other species, their stomachs being filled with the dark mud matter on which they continue to feed. Aside from this difference the two species are similar in their juvenile characteristics, i.e., they have cyclid scales, no adipose eyelid, and but two anal fin spines.

The *development of the scale* though mainly similar to that of the striped mullet is interestingly different. The juvenile scale differs from that of *M. cephalus* in a tendency toward one pair less of basal radii and in tending to have lateral circuli connecting anterior and posterior circuli (figs. 16–19). The lowest formula found was a 10, l.0, p. 14, thus being more advanced than corresponding *M. cephalus.* As these juvenile fish acquire their adult characters the habit of sculpture of the basal area of the scale changes in the same way as does that of *M. cephalus.* The development of the apical portion of the scale, on the other hand, is strikingly different. In *M. cephalus* the lateral circuli generally extend backward following the contour of the juvenile scale until they meet and thus form about it a close fitting frame. This is so foreign to *M. curema* that it only rarely occurs and then only with the first circulus. The second one in extending backward tends to diverge from the first, the third from the second though possibly less, and so on (figs. 16–19). This occasionally occurs in *M. cephalus* scales (fig. 15) but only with a few circuli. The typical lateral circulation for *M. curema* scales is this divergent type but without the close-fitting lateral circulus, the very first one forming an acute angle and terminating very briefly at the edge of the juvenile scale or continuing through it as an apical circulus. Meanwhile each apical circulus has done one of two things, it has entirely stopped growing or it has continued to grow. If all apical circuli cease growing at the same time another apical circulus may form about them as above described (figs. 16–19) and thus very definitely mark off the juvenile scale as in the other species, but, unlike it, this new circulus is close to the juvenile scale and immediately followed by others so that the apical circuli are much more closely spaced than in the jumping mullet. (Compare figs. 16–19 with figs. 12–15). If all the apical circuli of the juvenile scale continue to grow in full strength and unchanged direction (of very rare occurrence) the apical boundary of the juvenile scale is undiscernible. Although these circuli will continue to extend across the transition line between the juvenile and young scale, until they meet lateral circuli or reach an equivalent distance, they generally become thin at the transition line, or, in rare cases, become obsolete at that point, (figs. 16, 17). Accompanying this weakness of growth the circuli will often become curved or more widely or irregularly spaced at the transition line, so that the boundaries of the juvenile scale are plainly discernible. The first few apical circuli of the juvenile scale never run beyond it, extending only to the line of the posterior axes where they occasionally turn and become lateral circuli. In the great majority of juvenile scales all apical circuli do not pursue the same course, so that the scales present an enormous amount of variation on the transition line (figs. 16–19). For this reason it is very rare when the juvenile scale is not set off from the remainder of the scale posteriorly, while it is always discernible anteriorly. When apical circuli meet lateral circuli they do so at an acute angle thereby forming a type of circulation quite characteristic of the scale of this species (figs. 17–19, 21). Figure 16 shows such an angle just formed, another about to form, and another some distance from forming. Thus, although there is not so striking a transition in the scale of *M. curema* as in *M. cephalus*, yet there is a change so marked as to be unexplainable. It is certain that this change in the scale sculpture is not due to migration for all stages of the change, and scales some time before the change would take place, are procurable as long as juvenile fish are obtainable, and further, the change is not merely a seeming cessation of growth for a short period, but a complete change in *sculpture habit;* nor is it due to change in diet for the intestine contents of the fish before and after the change, in the scale, are alike. Thus again the change seems to be recapitulatory or phylogenic. A factor in the destruction of the central sculpture, and more so than in the other species, is the spreading of the lateral line groove (figs. 17, 18).

After a various number of apical circuli have been formed (generally more than in *M. cephalus*) a break appears at the apical center in which cteni are formed (figs. 18, 19, 21). These cteni are added and develop much as in *M. cephalus*, but have an entirely different appearance. Instead of being narrow, slightly curved, keeled, and sharply pointed as in *M. cephalus*, the cteni of this species are wide and flat with a very inconspicuous keel at the apical end (figs. 27, 28). Moreover, the cteni in *M. curema* practically all appear in a well defined projecting band while in *M. cephalus* they gradually merge back into the old worn stubs of former teeth called by Cockerell (1913) "apical marginal elements" (herein, for brevity, called ctenobasii), and do not project as a well-defined band beyond the normal outline of the scale except in very advanced scales (fig. 26). In figure 27 notice how the ctenobasii seem in places to be broken up circuli and in others worn down cteni, as though the cteni were modifications of the circuli. In *M. curema* (fig. 28) the transition is not so gradual, the fringe of cteni seeming quite segregated from the remainder of the scale. The ctenobasii, however, are present in even greater numbers than in the other species and although they do not seem to be worn down cteni they occupy an area once covered by them (figs. 18, 19, 21). They must therefore be considered deteriorated cteni and noted as another difference between the two species. The cteni are added row after row along with the circuli throughout the summer until the fish have reached a maximum size of 230mm. in September when they migrate south. Figure 21 is from a scale of a 121mm. fish taken on the 23rd of August, and shows all the characteristics of the scale of this species. Compared with figure 20 (the corresponding scale of the other species) the radii are seen to be fewer in number. This is constantly the case. Both these scales having been taken from the same position on the fish's body, this difference is a real specific difference. The lateral circuli are also more closely spaced in *M. curema* than in *M. cephalus* in scales of equal size. This does not mean that one species accrues circuli at a greater rate than the other.

Migration

In the fall the scattered individuals and small schools gather over the sandy bottoms in schools of ever increasing size, much as do the other species, and each school in its turn migrates leisurely south. During the winter this mullet is very rarely if ever found in the Beaufort region but with the approach of summer an occasional individual may be taken. It is, however, so uncommon in its second season or older, that the fishermen consider it a matter of curiosity or note when one is caught. Several specimens about eight inches long were taken on the 27th of June. From the scale formula of an individual 184mm. long (1.67+26) there seems to be little doubt that this fish migrated in the early spring. Three other scales from fish bearing no data show a similar linea, but situated farther from the edge of the scale.

Adults

Due to the scarcity of this species at Beaufort no true adults were procured so that practically nothing is known concerning their habits. From figure 3 it is evident that the spawning period must be rather protracted and, if an estimate of the time can be made from the dates when the smallest fish are procurable the season would be (conservatively) from mid-April to mid-August, the height of the season probably being in May.

Summary

Mugil cephalus Linné

1. To the synonymy of the genus *Mugil* should be added *Querimana*.

2. To the synonymy of the species *M. curema* should be added *Q. harengus*, its juvenile young.

3. *M. cephalus* spawns in October and November (September to December).

4. The juvenile young pass the winter without much growth.

5. In the spring the juvenile change diet and grow very rapidly until fall when they school and migrate south not to return until spring.

6. In the spring, the young, at that time from five to eight inches long, return north by a (typically) continuous run.

7. By the second fall the fish have reached a length of a foot or more and attained maturity.

8. In October and November these two-year-old fish migrate south spawning as they go.

9. Jumping mullet may attain an age of five or six years, spawning each year after maturity.

Mugil curema Cuv. & Val.

1. *M. curema* spawns in May and June (April to August).

2. The young are abundant in the bays and estuaries of our Atlantic coast and develop rapidly.

3. In the fall the young school and migrate south.

4. After their first year, white mullet are but seldom caught north of Florida.

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EXPLANATION OF PLATES

Plate XX

Fig. 8. Juvenile scale from smallest fish normally obtainable (23 mm. fish), x 45.

Fig. 9. Juvenile scale with maximum amount of development (32 mm. fish). x 45.

Figs. 10–14. Juvenile scale being enclosed by the more advanced type of scale (29 mm.—45 mm. fish), x 45.

Plate XXI

Fig. 15. Scale of a 60-70 mm. mullett with cteni first forming, x 45.

Figs. 16–17. Juvenile scale being enclosed by the more advanced type of scale, x 45.

Figs. 18–19. Development of cteni on scale of the white mullett, x 45.

Plate XXII

Fig. 20. Typical scale of advanced first season jumping mullett, x 25.

Fig. 21. Typical scale of advanced first season 121 mm. white mullet taken August 23, x 21.

Plate XXIII

Fig. 22. Scale of a 117 mm. mullet with unusual amount of circulation, x 30.

Fig. 23. Scale of 120 mm. jumping mullet taken April 28 with linea very near margin, x 25.

Fig. 24. Scale of jumping mullet, with a double linea, x 30.

Plate XXIV

Fig. 25. Typical scale of second season jumping mullet. x 30.

Plate XXV

Fig. 26. Scale of a five year jumping mullet 502 mm. (20 inches) long. x 13. Development of scale of *M. curema*.

Plate XXVI

Figs. 27–28. Ctenoid area of scales of adult *M. cephalus* and *M. curema*, highly magnified.